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Assessing students' arguments made in socio-scientific contexts: The considerations of structural complexity and the depth of content knowledge

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Abstract

Socio-scientific issues require students to generate informed decisions supported by their arguments. Yet the deliberations between structure-dominant and content-dominant analytical frameworks continue as to what is considered an informed decision. The intent of this paper is to propose a Modified Toulmin Argument Pattern (ModTAP) analytical framework that attempts to take into account both structural complexity and depth of content knowledge embedded in students' arguments. The holism of the ModTAP analytical framework is argued, in comparison to selected existing analytical frameworks. It is proposed that the ModTAP can overcome some of the antagonistic issues between structure-dominant and content-dominant analytical frameworks.

Keywords: Assessment, socio-scientific issues, argumentation, analytical framework;

1. Introduction

As the world is confronted with various conflicts, there is ample research as to how to foster students' argumentation skills (Kolsto, 2006). People have to make informed decisions about socio-scientific issues, which subsequently could impact their lives (Dawson & Venville, 2009; Halverson, Siegel & Freyermuth, 2009; Osborne, Erduran & Simon, 2004; Patronis, Potari & Spiliotopoulou, 1999). Since students are the future adults (Maloney, 2007), their argumentation skills related to socio-scientific issues are of concern, and have been studied (Chang & Chiu, 2008; Erduran, Simon & Osborne, 2004). However, educators themselves have different views in defining what an informed decision is.

In the assessment of argumentation, there are two major types of analytical frameworks. First, the structure-dominant perspective considers the role played by each structural component and how all structural components assemble to form a strong foundation. For instance, the well accepted Toulmin's structure of assessment (1958) has been a normative analytical framework (Kolsto, 2006). Toulmin proposed 6 structural components: claim, data, warrant/s, backing/s qualifier and rebuttal. Interpreting his idea in the socio-scientific context, a claim is the decision made and the data would provide factual information. Warrants are statements to justify the data whereas the backings provide an authoritative foundation to the warrants. A qualifier serves as the condition when the decision

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stays true and the rebuttal refutes the condition when the decision is no longer true. According to this framework, the persuasiveness of an argument lies on the fulfillment of all structural components. However, more than 80% of students' arguments contained incorrect or irrelevant scientific knowledge in natural classroom settings (Zohar & Nemet, 2002). In dealing with socio-scientific issues, students must adopt a scientific lens through which they can put forward their arguments (Halverson et al., 2009). Hence, Toulmin's scheme does not consider the validity of scientific knowledge demonstrated in students' arguments (Sampson & Clark, 2008). On the other hand, content-dominant analytical frameworks emphasize on the depth of content knowledge demonstrated in students' arguments. For instance, depth of content knowledge refers to the relevancy, specification and validity of the scientific knowledge presented (Zohar & Nemet, 2002). However, several analytical frameworks (e.g., Castano, 2008; Zohar & Nemet, 2002) do not require students to indicate the need to clarify conditions when decisions need to be changed. For instance, asbestos used to be a major material in fire and roof proofing due to its good heat resistance. Nevertheless, when later it was found to be hazardous to health, warnings were given and people do not use asbestos after knowing its link to cancer (Environmental Protection Department, 2006; National Cancer Institute, 2009). Therefore, students should indicate the limitation of their decision in a real life context (Chang & Chiu, 2008; Patronis et al., 1999).

The strengths that lie in both structure-dominant and content-dominant analytical frameworks provide educators the basis for assessing students' argumentation skills. However, the authors are of the opinion that each by itself does not provide a holistic base to analyze how well students can argue (Sampson & Clark, 2008). Therefore, the aim of this paper is to propose an analytical framework which emphasizes both structural complexity and takes account of the depth of content knowledge articulated in students' arguments. If the connection between the two constructs is linked, it provides a more wholesome platform for educators and researchers to assess students' argumentation skills (Sampson & Clark, 2008).

2. Literature review

What are arguments? What are the components of arguments? The literature review discussed here is an overview of what are considered as components of a persuasive argument.

2.1. Decision

A decision is a claim of one's stand before arguing (Toulmin, 1958), and recent analytical frameworks define a decision as the basis of an argument (e.g., Osborne et al., 2004; Maloney, 2007). Nevertheless, when dealing with socio-scientific issues, having no decision is also a decision (Kolsto, 2006).

2.2. Grounds

Irrespective of what decision one has made, one should support it with grounds (Toulmin, 1958). Toulmin (1958) defines grounds separately, namely as data, warrant/s and backing/s and many studies (e.g., Bell & Linn, 2000; Eskin & Ogan-Bekiroglu, 2009; Kelly, Druker & Chen, 1998; Kolsto, 2006; Patronis et al., 1999) have tried to categorize students' grounds into data, warrant/s and backing/s, but several researchers (Chang & Chiu, 2008; Dawson & Venville, 2009; Kelly et al., 1998) highlight the difficulties in distinguishing between data, warrant and backing. Efforts have been made to modify Toulmin's idea. For example, Osborne, Erduran and Simon (2004) collapsed data, warrant/s and backing/s into a single category.

Quality of grounds includes the richness of the description. However, guidelines are needed to differentiate between a brief description and a detailed description. Several researchers (e.g., Chang & Chiu, 2008; Zohar & Nemet, 2002) have attempted to measure the richness of grounds quantitatively. According to them, each ground is given a statistical score. They agree that the quality of an argument increases with the number of grounds. For instance, an argument which has no ground would be rated as "0". Nevertheless, they have contradictory views of the maximum quantitative contribution of grounds in an argument. Zohar and Nemet (2002) rate the highest score "2" for arguments with two grounds and above. Chang and Chiu (2008) disagree. They claim maximum scores should not be limited. Irrespective of the way to quantify the grounds, both ideas have successfully registered a high (> 0.8) inter-rater reliability. From a qualitative perspective, detailed descriptions such as real examples are

convincing (Castano, 2008). Extended lines (i.e., elaborations) also enrich the grounds (Ekborg, 2008; Zohar & Nemet, 2002). However, the qualitative boundaries between brief and detailed descriptions are difficult to distinguish (Kelly & Takao, 2002). As a result, Kelly and Takao (2002) reported relatively low agreements in coding between six levels rubrics of description. Furthermore, as students tend to repeat the grounds (Maloney, 2007; von Aufschnaiter et al., 2007), further guidelines are needed to avoid assessing repeated grounds.

Another aspect is that all grounds should be assessed for general, invalid and irrelevant scientific knowledge (Zohar & Nemet, 2002). Students face socio-scientific issues which comprise of uncertain knowledge claims (Maloney & Simon, 2006; Simonneaux, 2001). How can they evaluate the integrity of uncertain knowledge claims (Kolsto, 2006)? Furthermore, subject-matter experts could differ in their perspectives of scientific knowledge (Kelly & Takao, 2002; Kolsto, 2006). In fact, authoritative knowledge should not be an issue to cease argumentation in socio-scientific issues. There is no absolute authoritative knowledge in socio-scientific issues because of their ill-structured and debatable nature (Sadler, 2004; Sadler & Donnelly, 2006). This controversial nature allows students to argue with their beliefs, which has no absolute right or wrong. For instance, Genetically Modified Foods (GMF) has emerged as a controversial issue. Proponents may support the production due to the consideration of its nutrition, yields and resistances to diseases (Huang et al., 2008; Jauhar, 2006; Qaim & Zilberman, 2003). On the other hand, the opponents may argue the risks on food safety, production costs, ecological and social impacts (Andow & Hilbeck, 2004; Chen et al., 2004; Chilcutt & Tabashnik, 2004; Cleveland & Soleri, 2005; Gealy, Mitten & Rutger, 2003; Goodman, 2004). Maloney and Simon (2006) realize that, if schools keep emphasizing on the absolute of science, then students would be isolated from the process of knowledge making prevalent among the community of scientists.

2.3. Rebuttals

One's ability to indicate the condition when a decision would no longer hold true would symbolize a higher cognitive skill (Chang & Chiu, 2008; von Aufschnaiter et al., 2008). Socio-scientific issues may contain contested and uncertain scientific knowledge (Maloney & Simon, 2006; Simonneaux, 2001). In the cases of the application of asbestos and the production of GMF, one's decision may change due to different considerations. Hence, students should indicate the limitation of his or her decision (Dawson & Venville, 2009; Erduran et al., 2004). In argumentation studies, Toulmin (1958) distinguished between a qualifier and a rebuttal. A qualifier acts to define the condition when a decision holds true, whereas a rebuttal indicates the condition when a decision does not. However, researchers (e.g., Dawson & Venville, 2009; Osborne et al., 2004) rarely employ both rebuttals and qualifiers. The rationale how both should be considered can be demonstrated by the examples below; it shows the equivalent role played by both rebuttals and qualifiers when dealing with GMF issues.

I would cut down trees to build houses, farms and factories as long as we replant the forest. (Qualifier)

I would not cut down trees to build houses, farms and factories unless we replant the forest. (Rebuttal)

In line with that, Chang and Chiu (2008) also applied positive heuristic, negative heuristic and protection belt to indicate the limitation and hypothesis made on a decision. This implies diverse terminologies but yet researchers have come to a consensus that the limitation of a decision put forward in a rebuttal would indicate a higher quality of argumentation skills. This quality is often lacking in argumentation and even undergraduate students have rarely exhibited the limitations of decisions when dealing with GMF issues (Chang & Chiu, 2008).

3. Methodology

The Modified Toulmin Argument Pattern (ModTAP) analytical framework (Table 1) was developed and employed to evaluate students' arguments in a Malaysian study. To highlight how the ModTAP analytical framework defines quality of argument, as well as the congruent foci of two selected analytical frameworks, two sample arguments were analyzed using aforementioned schemes. The sample arguments were generated by students during an instructional task. Students were asked to answer the following question, "Would you cut down trees to

build houses, factories and farms?" in reporting their arguments. It was noted that, grammar was not an aspect of evaluation and students' grammatical errors were corrected for better comparison.

Sample argument 1:

No, I will not cut down trees to build houses, factories and farms because cutting down the trees will increase the carbon dioxide and decrease the oxygen. This can cause the weather of the whole world to change and become hotter and cause the ice in mountains to melt and cause floods. Besides this, cutting down the trees to build houses, factories and farms will cause soil erosion because the soil does not have the roots of trees to protect it. Cutting down the trees to build houses, factories and farms will also destroy the habitats of animals in the jungle. However, if there are ways to protect the habitats of animals and the ways to decrease the carbon dioxide in the air, I will cut down trees to build houses, factories and farms.

Sample argument 2:

I will not cut down trees to build houses, factories and farms because it will cause green house effect.

Table 1. Modified Toulmin Argument Pattern (ModTAP) Analytical Framework

Quality	Description of Argument
Level 0	No decision is made explicitly or implicitly, with/out supported by valid grounds and rebuttal.
Level 1	A decision without supported by valid grounds and rebuttal.
Level 2	A decision supported by valid grounds, but without rebuttal. Brief description of grounds (one or two grounds and with/out real example or elaboration).
Level 3	A decision supported by valid grounds, but without rebuttal. Detailed description of grounds (three grounds and above, have real example or elaboration).
Level 4	A decision supported by valid grounds, and contains rebuttal. Brief description of grounds (one or two grounds and with/out real example or elaboration).
Level 5	A decision supported by valid grounds, and contains rebuttal. Detailed description of grounds (three grounds and above, have real example or elaboration).

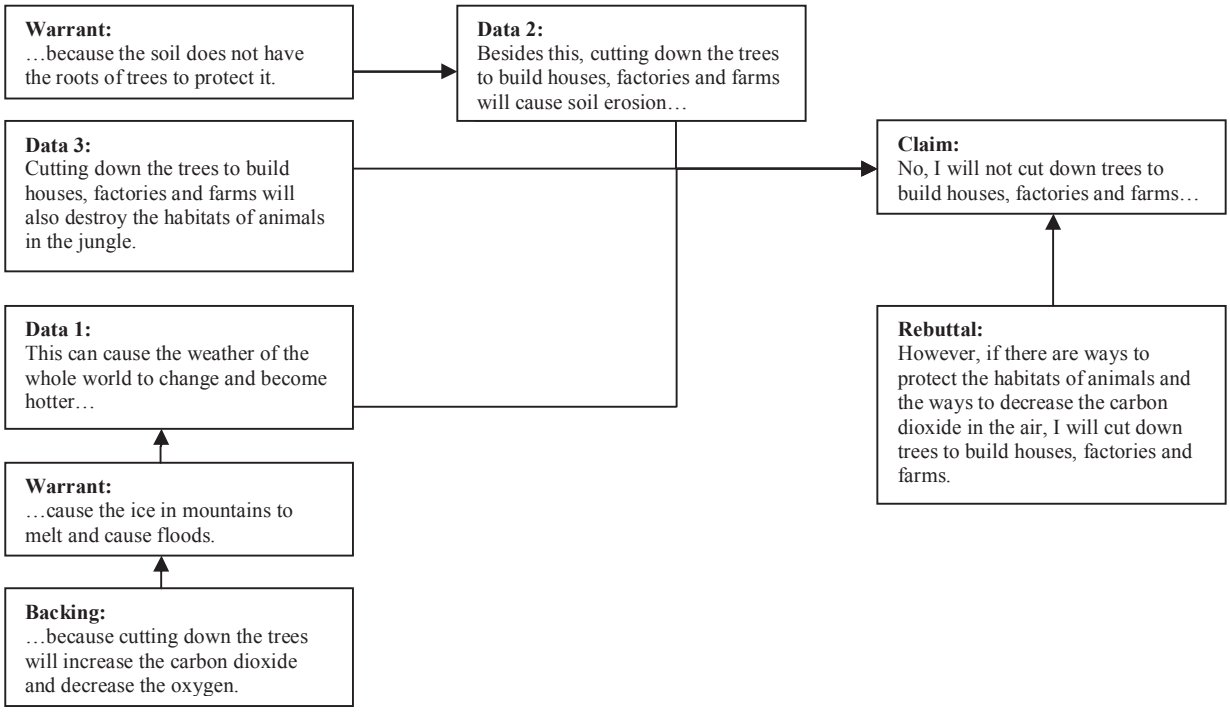

Figure 1. Analysis of sample argument 1 using Toulmin's scheme (1958)

4. Results and Discussions

The researchers first considered the Toulmin's scheme (1958), which is a structure-dominant analytical framework. The analysis suggested the sample argument 1 had fulfilled the majority of the structural components; hence this sample argument was relatively persuasive (Figure 1).

The sample argument 1 was then rated employing the thoughts of Zohar and Nemet (2002), which is a content-dominant analytical framework. According to this framework (Table 2), the sample argument contained more than 2 justifications. These justifications also demonstrated relevant and correct scientific knowledge. Furthermore, there were extended lines (i.e., the cause and consequences) to support the justifications. Hence, the sample argument was highly rated.

Table 2. Analysis of sample argument 1 using thoughts of Zohar and Nemet (2002)

Statements made	**Depth of content knowledge**	**Coding**
No, I will not cut down trees to build houses, factories and farms…	-	Decision made
…because cutting down the trees will increase the carbon dioxide and decrease the oxygen.	Correct and relevant	First justification
This can cause the weather of the whole world to change and become hotter and cause ice in the mountains to melt and cause floods.	Correct and relevant	Extending the first justification
Besides this, cutting down the trees to build houses, factories and farms will cause soil erosion…	Correct and relevant	Second justification
…because the soil does not have the roots of trees to protect it.	Correct and relevant	Extending the second justification
Cutting down the trees to build houses, factories and farms will also destroy the habitats of animals in the jungle.	Correct and relevant	Third justification
However, if there are the ways to protect the habitats of animals and the ways to decrease the carbon dioxide in the air, I will cut down trees to build houses, factories and farms	-	General extending lines
Total score	i) Score for justifications: 2/2 ii) Score for structure: 2/2	**Total: 4/4**

Lastly, the sample argument 1 was rated accordingly to the analytical framework proposed in the paper, ModTAP analytical framework (Table 3). As shown in the table, the sample argument 1 contained 3 valid grounds and elaborations. Furthermore, it posted a reasonable rebuttal. Therefore, it deserved to be at the highest quality.

Table 3. Analysis of sample argument 1 using ModTAP analytical framework

Decision	**Competency of grounds (Valid/ Invalid/ General/Irrelevant)**	**Rebuttal**	**Level**
No, I will not cut down trees to build houses, factories and farms because…	**Valid Ground 1:** …because cutting down the trees will increase the carbon dioxide and decrease the oxygen. **Elaboration:** This can cause the weather of the whole world to change and become hotter and cause ice in the mountains to melt and cause floods. **Valid Ground 2 & Elaboration:** Besides this, cutting down the trees to build houses, factories and farms will cause soil erosion because the soil does not have the roots of trees to protect it. **Valid Ground 3:** Cutting down the trees to build houses, factories and farms will also destroy the habitats of animals in the jungle.	However, if there are ways to protect the habitats of animals and the ways to decrease the carbon dioxide in the air, I will cut down trees to build houses, factories and farms.	**5**

For the comparison of sample argument 2, by utilizing Toulmin's scheme (1958), the sample argument 2 had neither a warrant nor a backing to strengthen the data (Figure 2). It also did not state a rebuttal to indicate the limitation of the decision. As a result, the sample argument 2 was rated weak due to its simplistic structure.

Figure 2. Analysis of sample argument 2 using Toulmin's scheme (1958)

The comparison of sample argument 2 adopting the thoughts of Zohar and Nemet (2002) is given in Table 4. The argument comprised of a single justification and without extended lines. The relatively fewer numbers of justification and a simplistic structure resulted in a poor score.

Table 4. Analysis of sample argument 2 using thoughts of Zohar and Nemet (2002)

Statements made	Depth of content knowledge	Coding
I will not cut down trees to build houses, factories and farms….	-	Decision made
…because it will cause green house effect	Correct and relevant	First justification
Total score	i) Score for justifications: 1/2 ii) Score for structure: 1/2	**Total: 2/4**

The ModTAP analytical framework found the sample argument 2 to be relative simple (Table 5). There was only one valid ground with no further elaboration or example. The argument also contained no rebuttals to indicate higher argumentation skills. Consequently, it was a weak argument.

Table 5. Analysis of sample argument 2 using ModTAP analytical framework

Decision	Competency of grounds (Valid/ Invalid/ General/Irrelevant)	Rebuttal	Level
I will not cut down trees to build houses, factories and farms….	**Valid Ground 1:** …because it will cause green house effect	Nil	**2**

Our analysis of students' arguments following the ModTAP analytical frameworks demonstrated the potential of this approach for shared notions of structural complexity and the depth of content knowledge. The comparison of the sample argument 1and 2 showed that some of the antagonist issues between structure-dominant and content-dominant analytical frameworks could be resolved.

The reliability of the ModTAP framework was found to be consistent with the overall views of qualitative coding (Kelly et al., 1998). Approximately 100 students' arguments collected from 3 different instructional tasks were coded independently by the researcher and the instructor of the instructional tasks. The initial analysis developed agreements above 85% of the students' levels of argumentation skills. According to Miles and Huberman (1994), this is a relatively high reliability.

However, it was also realized that, the ModTAP analytical framework is not unproblematic. In this present study, students wrote extended lines to support their grounds. The categorization of "example" and "elaboration" was a subtle affair for the researchers. Subsequently, peer review was conducted to explore further evidences. Interestingly, each of the 4 reviewers found categorizing the extended lines into "example" and "elaboration" was easily distinguishable. Nevertheless, the results of the review codes were not congruent across 4 reviewers. For example in the student's statement below,

> GM crops bring higher economic value to us. As an example, maize and rice production may not be much; after it is GM, it can produce more.

Reviewer A commented the second sentence was an example and it was at odds with the category assigned by Reviewer B. Although example and elaboration might be defined differently, all reviewers came to a consensus that regardless of the notions being adopted, extended lines should be accredited for its role to enrich the grounds. Many analytical frameworks (e.g., Castano, 2008; Chang & Chiu, 2008; Kelly & Takao, 2002; Zohar & Nemet, 2002)

including the ModTAP appreciate valid grounds, but these analytical frameworks have not explained, how invalid ground/s would influence the overall quality of an argument. In other words, between a simple argument (which has relatively less number of valid grounds but without invalid or incompetent grounds) and a complex argument (which has more numbers of valid grounds but also with incompetent grounds), which argument demonstrates a higher quality? For example,

> The reason that I would not cut down trees because it could causes ecological imbalance. Then, cutting down trees also damages the habitats of animals and plants. This also damages the sources of food of some species, example like the panda, it only eats sugar cane.

In the student's argument above, the justifications are reasonable except for "example like the panda, it only eats sugar cane". Accordingly to the ModTAP analytical framework, invalid grounds are not given credit, but they do not reduce the quality of the argument. Students might take advantage to guess the correct scientific knowledge, rather than looking into the integrity of information independently. Is this evaluation method appropriate? In order to answer this question it will require new approaches to examine these aspects through future research.

5. Conclusion

An analytical framework is not merely a tool for evaluation. It is also a guide to the teaching of argumentation skills. Instruction to enhance students' content knowledge alone does not increase their skills in making decisions pertaining to socio-scientific contexts (Sadler & Donnelly, 2006). Teaching students the skills to argue must include the ability to differentiate persuasive and weak arguments (Zohar & Nemet, 2002). Furthermore, the teaching of argumentation skills has to be explicit (Kuhn, 1991; Zohar & Nemet, 2002). Before engaging students in argumentation, they need to recognize the demands for an informed decision and know the rules thoroughly (Osborne et al., 2004; Perkins & Salomon 1989; Sadler & Donnelly, 2006). A persuasive argument should not be underscored due to the discrepancies of analysis, and a weak argument must not be appreciated due to analytical warp (Sampson & Clark, 2008).

This paper has argued the strengths that lie in structure-dominant analytical frameworks as well as content-dominant analytical frameworks. Such an analytical framework can be great use for the assessing of students' argumentation skills and can enable the sharing and comparison of findings among educators and researchers (Sampson & Clark, 2008). The paper has suggested the synthesis of particular strengths from two types of frameworks as a useful research tool to investigate students' argumentation skills holistically.

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